

## The Development and Implementation of Ground Safety Requirements for Project Orion Abort Flight Testing – A Case Study

### Introduction

A rigorous set of detailed ground safety requirements is required to make sure that ground support equipment (GSE) and associated planned ground operations are conducted safely. Detailed ground safety requirements supplement the GSE requirements already called out in NASA-STD-5005.

This paper will describe the initial genesis of these ground safety requirements, the establishment and approval process and finally the implementation process for Project Orion. The future of the requirements will also be described. Problems and issues encountered and overcome will be discussed.

### Overview of Crew Exploration Vehicle (CEV) Abort Flight Test (AFT) Project

The AFT project is designed to demonstrate the capabilities of the Launch Abort System (LAS), through a series of full scale flight tests. The purpose of the LAS is to save the crew should a contingency situation occur on the launch pad (pad abort) or during early phases of ascent (ascent abort). A launch escape system has been used once before to save a Russian crew from a launch pad conflagration. The Crew Exploration Vehicle (CEV) AFT plan is to conduct two pad abort tests (Pad Abort (PA)-1 and PA-2) and three ascent abort (Ascent Abort (AA)-1, AA-2 and AA-3) tests. The three ascent tests will initiate aborts at the maximum dynamic pressure condition and two aborts will be initiated at a transonic condition – one nominal attitude and one off-nominal attitude. The test conditions for the ascent abort tests will be attained by utilizing a booster motor that will loft the Crew Module (CM)/LAS to the desired LAS abort initiation test point. Per the current schedule, PA-1 is to launch first followed by AA-1, PA-2, AA-2 and AA-3, respectively. The results of these engineering demonstration tests will be used to build confidence in the LAS and CM designs. Results from these flight tests support hardware certification efforts from the standpoint that the data can be used to anchor critical CEV analytical models. The LAS, while considered as an emergency use system is, nonetheless, critical in mitigating the overall Loss Of Crew (LOC) risk for the Constellation Program. Early on, in preparation for the equivalent of System Requirements Review (SRR) for PA-1, a set of flight test objectives were generated. These test objectives are documented in CxP 72216, "Project Orion Flight Test Vehicle Mission and Flight Test Objectives". As the Project learns more, these test objectives have been and will be updated to get the most out of these expensive, but high value, flight tests.

Due to the need to test the LAS design early, before production CMs were available, unique arrangements were struck between the NASA design and operations centers and Lockheed Martin (LM), the prime contractor for the CM,

Service Module (SM), and LAS. For the first two flight tests structurally similar CMs (same Outer Mold Line (OML) as the production vehicle) are to be built by NASA Langley Research Center. Also, for the first two test flights, the LM-provided LAS are to be "production like", with some notable differences. The LM-provided avionics, which control CM and LAS event functions during the test, is also "production like" (commensurate with the maturity of these systems). NASA Johnson Space Center provides the CEV Parachute Assembly System (CPAS), NASA Standard Initiators (NSIs), and the frangible nuts that provide the structural attachment between the LAS and the CM. Finally, NASA Dryden Flight Research Center (DFRC) provides the Developmental Flight Instrumentation (DFI) system and instrumentation to obtain the important flight test data. All of this new flight hardware requires the design and procurement of literally hundreds of pieces of Ground Support Equipment (GSE) (provided by NASA and LM) as well as the development of new operational procedures to perform the necessary ground operations. Furthermore, ground operations are to occur at two primary locations – DFRC and WSMR. Much of the low hazard flight test article build-up is to occur at DFRC while the hazardous operations, including build-up of the LAS (three solid rocket motors) and installation of mortars and pyrotechnics is to occur at WSMR.

The task of integrating all of this together was truly complex and the desire to do things similarly was important. Also, there existed a consideration that some of the GSE that was being built to support the abort flight test program might eventually be utilized in support of production vehicle build-up or during ground processing flows. Therefore the desire to build this equipment right the first time was certainly a financial consideration. Finally, a number of different safety cultures existed, with specific experiences and knowledge base that also had to be fully integrated. The U.S. Army safety personnel that were assigned to support the abort flight test program at WSMR informed NASA that the GSE hardware and associated hazardous operations needed to be controlled by a strict set of safety requirements. The Army was receptive to a uniquely tailored set of ground safety requirements developed by NASA in lieu of imposing Air Force Space Command Manual (AFSCMAN) 91-710, which is the all encompassing set of ground safety requirements typically imposed by the military for their projects. This inter-agency arrangement required the approval of these safety requirements by the WSMR base commander.

#### Establishment of Need

In April 2007, during PA-1 Project Technical Review-2 (PTR-2) (equivalent to a Preliminary Design Review (PDR), in terms of design maturity), an action was issued by the Project Orion Project Technical Review (PTR) Technical Review Team (TRT) (evaluation board) to establish a tailored set of ground safety requirements to be used for CEV Abort Flight Testing. These requirements were to be flowed down to GSE, the flight test articles, and ground operations. The need for these requirements was driven by the project's plan to conduct testing at

NASA's Dryden Flight Test Center and the U.S. Army's White Sands Missile Range (WSMR). WSMR required that a rigorous set of ground safety requirements be established to ensure the safe conduct of ground operations on the Range. As might be expected the various design teams, spread across the USA, that were already well into their design activities were concerned about how these safety requirements might impact their development efforts.

The abort flight test safety team, which was assigned to tackle this problem, was a partnership between safety personnel from a number of NASA centers and the prime contractor for Orion, Lockheed-Martin. Since NASA DFRC was an aeronautical flight test center having little experience with solid rocket motors and NASA JSC was primarily a flight center it was obvious that for this effort to succeed the team needed expertise from NASA Kennedy Space Center (KSC), NASA's primary center for spaceflight ground operations. NASA KSC ground safety experts officially joined the CEV abort flight test safety team in March 2007. With this addition the safety team had sufficiently diverse expertise to tackle the problem. From late May through early July 2007, the abort flight test safety group underwent an intense effort to generate a tailored set of ground safety requirements for the CEV abort flight test project. The methodology and approach taken by this safety group will be discussed in detail in another section of this paper. In July 2007, these safety requirements were mature enough to be flowed down to the various elements and potential design impacts were rectified. In October 2007, the Orion Project officially approved these requirements for use on the CEV abort flight test project and the WSMR base commander approved the document for use at WSMR several months later. The document was given the number and title, CxP 72213, "Project Orion Ground Safety Design and Operational Requirements." This was the first set of safety requirements to be established for Project Orion. Somewhat surprisingly, many of the design, operations, and management personnel actually found these requirements to be helpful to them as the design and operations activities continued to mature. It was not unusual to see this document quoted during design and operations presentations in support of some of the decisions that were being made.

During the development of CxP 72213, the CEV abort flight test safety team consulted a large number of technical experts to ensure the best set of safety requirements possible. The safety team would be remiss to not thank the myriad of experts that contributed their expertise to this effort.

#### Identification of Source Documents

A decision was made early in the process to use existing NASA ground safety documents as the basis for the CxP. KSC has a long history with ground safety for both manned and unmanned vehicles and payloads. The primary documents used were Kennedy Hand Book (KHB) 1700.7, "Space Shuttle Payload Ground Safety Handbook" and Kennedy NASA Procedures and Requirements (KNPR) 8715.3, "KSC Safety Practices Procedural Requirements". In addition,

AFSCMAN 91-710, other subject matter experts and the team's personal experiences were used to fill in known gaps in the basic source documents related to unique AFT issues.

What made KHB 1700.7 such a particularly good book to serve as a basis for ground safety was its long history of use and the fact that the document was originally developed as a joint use book by the NASA and United States Air Force (USAF) launch sites. This "jointness" was important in obtaining WSMR concurrence with the AFT project developing its own set of requirements. The KHB primarily brought a set of safety design requirements to the process. However, the KHB did have its weaknesses. The two biggest areas were graphite-epoxy Composite Overwrapped Pressure Vessels (COPVs) and batteries, especially lithium based. Both of these areas have been very dynamic in recent years. Consulting the subject matter experts in these fields resulted in up to date requirements for COPVs and batteries. Other minor deficiencies were also updated based on the personal experiences of the team.

The other important contributor to the CxP was KNPR 8715.3. This KSC document also had a long history of use, capturing lessons learned as far back as the Apollo Program and up to the present time. What distinguishes the KNPR from the KHB is that it is primarily a set of operational requirements. Where the two documents overlapped, the more stringent requirement was adopted.

By using these existing documents the team was able to, in less than six months, put together a comprehensive set of ground safety documents unique to Project Orion.

#### Pulling It All Together

To accomplish this process, a team of experts, NASA, Army and Contractor, was drawn together to sift through the source documents, draw out the applicable requirements, identify any gaps, fill those gaps and publish a single document for use. Several face to face meetings were held as well as numerous telephone conferences. Knowing the difficult task ahead, the team jelled quickly, thus meeting the quick turnaround time needed to get these requirements in the hands of GSE and Flight Hardware developers. Gaining approval from WSMR was also critical, for with WSMR approval, the Project would have been required to comply with the very detailed requirements of AFSPMAN 91-710.

Also participating in the development were representatives of the Project Office. While not safety experts, they assisted the Team in tightening up the requirements by questioning how each shall statement (i.e. requirement) needed to be verified. This give and take helped establish a good set of requirements. And at the end of the process, both the safety and Project Office representatives were both still talking to each other.

However, in spite of a Team's best efforts, no document is perfect. It can only be a first approximation at best. This was discovered when the document was released for review within the Project and supporting organizations. A vast majority of comments received pointed out deficiencies that were obvious in hindsight. The value of outside reviewers was amply demonstrated. Again, these personnel enhanced the validity of the document. As is usually the case, some compromises were made in order to gain approval. These compromises were mostly in the area of the Scope of the document. Technical compromises were based in sound reasoning.

The CxP 72213 is truly a living document. With each day, new interpretations are needed based on the lessons being earned in first time operations. At the present time (Fall 2008), the document is undergoing its third revision. This is not a bad thing; but rather demonstrates continuous improvement is at work.

### Issuing and Implementing

Once the document was written and reviewed for comments, it was presented to Project Orion Management for approval. As previously mentioned, the primary sticking point in final approval was how to scope the document. The original version of the document had been written at a Project level; that is, for use from production through all testing and processing leading up to a crewed launch. However, there were many strenuous objections to this broad of scope. When brought before the Project Orion Manager at the Project Control Board, a compromise was worked out that kept the overall tone of the document at the Project but limited its initial scope to the AFT project only. This compromise allowed for broadening of the scope at a future date, if so desired.

With this approval, the document was presented to the WSMR safety community. Upon their review, they endorsed the document and presented to the WSMR Commander, who also agreed that the document was sufficient to meet the requirements of the Range. This was an important milestone as it gave the AFT Project the confidence to proceed.

Implementation has been mildly difficult. This has been the result of the compressed schedule of the Project relative to having its requirements in place. It seemed as if the safety community was always running to catch up. Adding to the difficulty was the training of personnel to work with a set of definitive safety requirements. This only fix to this situation has been time. As the operations and safety communities work out each issue, the overall process becomes more stable, thereby decreasing the risk. This is important as the Project moves towards live testing at WSMR.

### Lessons Learned

The following is a summary of the lessons learned from this effort.

Any Team developing requirements must think ahead. They must know what the final goal is. Without this vision, it is very easy to get bogged down in the minutia of day-to-day operations or locations. Requirements should be written at a high enough level to be applicable across the program, without being so general as to be meaningless. Specific implementation of requirements should be left to lower level documents.

Although Project Orion is a “new” project, very little of the Project is so new as to need never before established requirements. Although existing requirements from other programs should be thoroughly reviewed, the simple fact they come from another program does not make them non applicable. Accept history as the basis for going forward.

Imposing safety requirements is a love/hate relationship. Projects do not inherently and deliberately design hardware to fail or be unsafe. Therefore there is a natural resistance to imposing new design and operational safety requirements especially after the requirement development period of the design cycle is over. However, by generating a good set of safety requirements the safety team is actually helping the design and operations teams to resolve issues within their areas. As a result they will thank you later (well maybe).

“One stop shopping” for safety requirements (i.e. all ground safety requirements compounded into one document) is not always the project mantra. Engineers prefer to have safety requirements that drive their design imbedded in their controlled design documentation. On the other hand, safety professionals, including independent review authorities (such as safety panel personnel), prefer having the safety requirements in a singular document under their control. Project management does not want requirements duplicated in multiple project-level controlled documents. The solution to this dilemma is not clear. For Project Orion, while the safety community has been relatively successful in keeping the ground safety requirements in one document; the flight safety requirements have been a different matter.

When working in the early stages of a testing program, it is important to be as flexible as possible in interpreting/enforcing the requirements. However, although flexibility is necessary, a firm line must be established to assure compliance. This is a difficult tightrope and can cause a considerable amount of stress.

As discussed above, the scope of the document is critical. Once the scope is agreed to, every effort must be made to ensure all the involved parties or stakeholders recognize the document. If not, it is highly likely GSE will show up that does not meet the requirements.

Finally, it is important to know the obstacles in the path to success. Recognizing these obstacles allows the Project to determine when to be flexible and when to be firm.

### Summary

In spite of a very compressed schedule, Project Orion's AFT safety team was able to pull together a comprehensive set of ground safety requirements using existing requirements and subject matter experts. These requirements will serve as the basis for the design of GSE and ground operations. Using the above lessons learned as a roadmap, new Projects can produce the same results.





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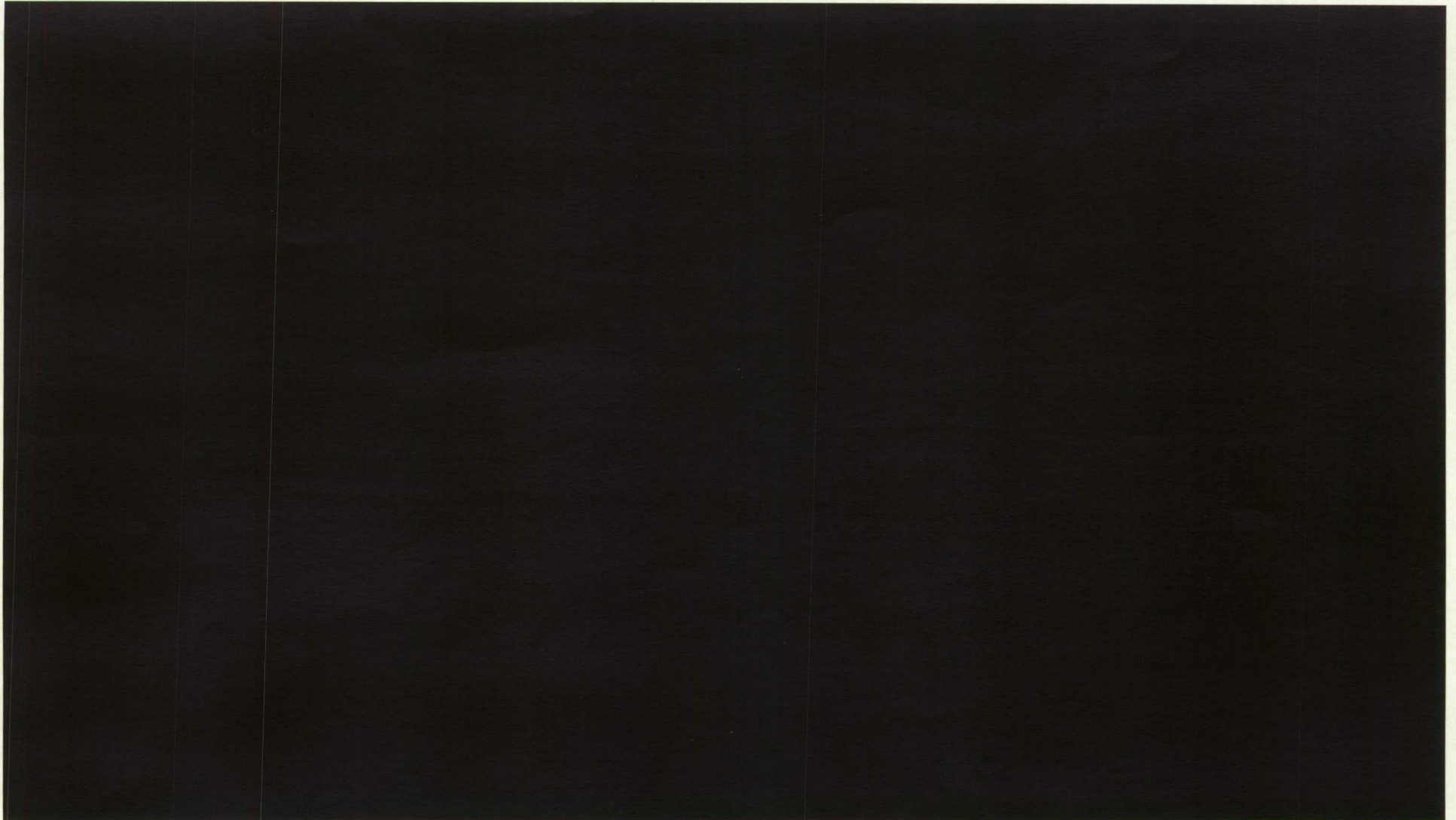


# Overview of Abort Flight Test

- Designed to demonstrate the capabilities of the Launch Abort System (LAS) for the Crew Exploration Vehicle (CEV) – Project Orion
- The LAS is critical in mitigating Loss of Crew risk during accidents on the Pad or in the early stages of flight
- Test program will be used to anchor analytical models
- A total of five flight tests are planned:
  - Two Pad Aborts
  - Three Ascent Aborts



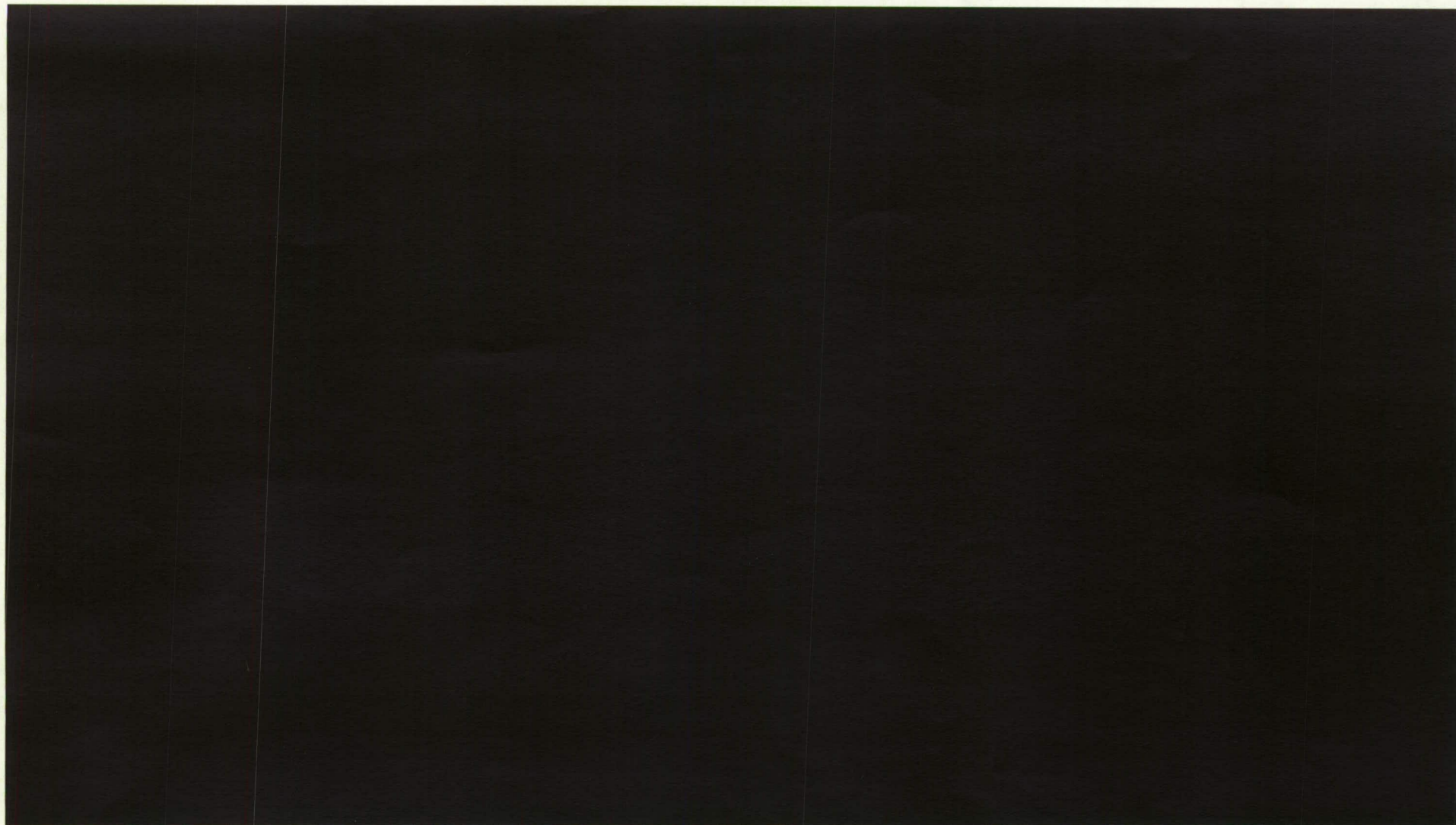
# PA-1 Video







# AA-1 Video





# Establishment of Need



- In the Spring of 2007 action assigned to develop a set of ground safety requirements for AFT
- Requirements meant to cover multiple locations, Agencies and Contractors





# Identification of Source Documents



- Use of Kennedy Space Center ground safety documents as basis:
  - KHB 1700.7, "Space Shuttle Payload Ground Safety Handbook"
  - KNPR 8715.3, "KSC Safety Practices Procedural Requirements"
- Supplemented with:
  - AFSPCMAN 91-710
  - Subject Matter Expert's personal experiences



# Pulling It All Together

- A team consisting of NASA and Contractor experts met in June 2007 to formulate the basic document
  - CxP 72213, “Project Orion Ground Safety Design and Operational Requirements”
- Document coordinated with design, operations and management personnel
- Approved by Project Orion and the White Sands Missile Range in Fall 2007





# Issuing and Implementing



- Determining Scope
  - Initial scope limited to Abort Flight Test
  - Requirements written at Project level for potential future re-scoping
- Range approval boost in confidence to Test Team
- Implementation:
  - Schedule relative to issuing of requirements
  - Training personnel in requirements
  - Time reduces risk





# Lessons Learned

- Think ahead
  - Know final goal
  - Keep requirements at appropriate level
- Accept history as a basis
- Requirements help design and operations teams
- One stop shopping for safety requirements
- Flexibility while holding a firm line
- Scope of Document/Obstacles



# Summary

- In spite of a very compressed schedule, Project Orion's AFT was able to pull together a comprehensive set of ground safety requirements using existing requirements and subject matter experts.
- Using the above lessons learned as a roadmap, new Projects can produce the same results.